CD-0, Approve Mission Need
for the
BTeV Project
at Fermi National Accelerator Laboratory

Non-Major Systems Acquisition

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Mission Need Statement
for the
BTeV Project
at Fermi National Accelerator Laboratory

Office of High Energy Physics
Office of Science

SYSTEM POTENTIAL: Non-Major System

A. Statement of Mission Need

The mission of the High Energy Physics (HEP) program is to explore and to discover the laws of nature as they apply to the basic constituents of matter, and the forces between them. The core of the mission centers on investigations of elementary particles and their interactions. One of these interactions being investigated is the phenomenon of Charge-Parity (CP) violation.

At some point very early in the evolution of the universe, the initial quantities of matter and antimatter became lopsided, or "asymmetrical," resulting in the matter-based universe we now know. Known as CP violation, that imbalance explains why, in the moments after the big bang, matter and antimatter did not annihilate one another and leave the cosmos empty. Understanding why and how the universe became asymmetrical is one of the most fundamental questions in the study of elementary particle physics today, and has profound implications for understanding how the whole universe evolved from its simple initial state to the complex patterns we see today.

Measurements from existing accelerators studying CP violations can account for only approximately one percent of the "asymmetry" needed to explain what we observe in the cosmos. Therefore, HEP is proposing the B-particle physics at the Tevatron (BTeV) as a new experiment for the Tevatron proton-antiproton collider (currently the world's most powerful accelerator) at the Fermi National Accelerator Laboratory (FNAL) to provide a powerful new tool with which to search for sources of the other 99 percent of the observed asymmetry. The experiment includes a new detector optimized to observe the decays of particles containing *b* or *c* particles (quarks) and to measure CP violation in their decays, and modifications to one interaction region of the Tevatron collider to increase the rate of interactions in the detector.

The BTeV Project also supports the Department of Energy's Science Strategic Goal within the Department's Strategic Plan dated September 30, 2003: *To protect our National and economic security by providing world-class scientific research capacity and advancing scientific knowledge*. Specifically, BTeV supports the two Science strategies: *1. Advance the fields of high-energy and nuclear physics, including the understanding of … the structure of nuclear matter in its most extreme conditions…* and *7. Provide the Nation's science community access to world-class research facilities….*

BTeV is identified as a near term priority in the Office of Science plan for the next twenty years: **Facilities for the Future of Science: A Twenty-Year Outlook**.

B. Analysis to Support Mission Need

CP symmetry relates the properties of particles to their antiparticles. However, unlike a perfectly conserved symmetry, such as conservation of energy or electric charge, CP symmetry has been discovered to fail in some limited circumstances. These small failures, or violations, of CP symmetry are very important to our understanding of the universe. CP violation is required to explain the fact that matter vastly outnumbers antimatter in the universe.

Since the early 1990s, experiments at the Stanford Linear Accelerator Center (SLAC) and the Japanese High Energy Accelerator Research Organization (KEK) have studied CP violations from the rare decays—specifically bottom (*b*) and charm (*c*) quarks. Because these events are so extremely rare, hundreds of millions of particles must be created to capture enough information for a single experiment. However, the CP violations observed so far are inadequate to explain that imbalance. There must be other sources of CP violation, and discovering these sources would be a major addition to our understanding of the universe.

By 2010 the B Factory at SLAC will have performed a thorough but incomplete survey of the physics of CP violation in quark systems. To complete this survey, access to states not produced by electron-positron interactions is mandatory, especially those which contain a bottom quark paired with a strange quark (B_s mesons). It is also crucial to examine the decays of many more B particles than can be produced at the B Factory.

The Tevatron at FNAL produces B particles at a 1,000 to 10,000 times greater rate than the B factories and produces all types of B particles, including B_s mesons and B baryons. The interactions containing B particles are significantly outnumbered by interactions that do not contain B particles, but state-of-the-art detector and computing technologies allow the unwanted interactions to be effectively filtered. This has lead to proposing the BTeV experiment, dedicated to studying CP violations using B particles produced at the Tevatron, to begin in FY 2010.

CP violation studies can also cross-check any discoveries at the LHC. For example, observation of new particles such as supersymmetric particles at the Large Hadron Collider (LHC) at the European Center for Nuclear Research (CERN) in Geneva, Switzerland, will imply new CP violation effects in the B meson system. Measurement of those effects then contributes to the correct identification of the newly observed particles as supersymmetric particles.

The importance of the physics addressed by BTeV has been endorsed twice by the High Energy Physics Advisory Panel (HEPAP). First, the Particle Physics Project Prioritization Panel (P5), a subpanel of HEPAP, reviewed BTeV along with the Run II Detector

Upgrades and the Charged Kaons at the Main Injector project. P5 endorsed the BTeV Project in its September 8, 2003, report stating:

> *P5 supports the construction of BTeV as an important project in the world-wide quark flavor physics area. Subject to constraints within the HEP budget, we strongly recommend an earlier BTeV construction profile and enhanced C-Zero optics.*

Second, HEPAP rated the science addressed by BTeV and the technical approach proposed by BTeV as "important" when advice was being solicited for input to the Office of Science's Report, "*Facilities for the Future: A Twenty Year Outlook*."

C. Importance of Mission Need and Impact If Not Approved

The DOE strategic goal to advance scientific understanding includes a strategy to study the lack of symmetry in the universe in order to reveal its key secrets. The study of CP violation falls under this strategy. Since the discovery of CP violation in the kaon system in 1964, it has been an important component of the DOE's high energy physics program. It was the main motivation for the construction of the B Factory, an electron-positron collider at Stanford Linear Accelerator Center (SLAC), where CP violation in the B meson sector was discovered in 1999 and will continue to be studied for several more years.

Various project scopes were evaluated, including the risk of doing nothing. There are four logical options for providing the facility needed to continue the study of CP violation.

Option 1: <u>Establish a dedicated B experiment at the Tevatron, such as BTeV.</u> BTeV was found to strike the right balance between cost and physics output. BTeV uses an existing accelerator, the Tevatron at FNAL. It can measure the decays of a wide variety of *b* particles with ample statistics. P5 has found that BTeV will be a more capable experiment than LHC-B. It can pursue a wider program and is better prepared to respond to new opportunities, owing to its more sophisticated detector and flexible data acquisition and trigger system. Some of these strengths emerge from using collisions at lower center of mass energy in the Tevatron. Bottom quarks produced at the LHC are more energetic and therefore more difficult to measure than at the Tevatron.

Option 2: <u>An upgrade to the accelerator at the SLAC B Factory and a nearly complete detector replacement, which is frequently referred to as a Super B Factory</u>. The concept for an upgraded accelerator and an almost completely new detector at the SLAC B Factory is still in its early stage of technical design and evaluation of its capabilities. It is expected that the Super B Factory would be significantly more expensive than BTeV, while BTeV would be able to measure a greater variety of decay modes of the *b* particles.

Option 3: <u>Participation by U.S. physicists in a dedicated B experiment at the LHC, LHC-B.</u> Participation in the LHC-B experiment at the LHC has not been pursued by the U.S. particle physics community. In 1997 when the DOE and the NSF entered an agreement with CERN regarding the LHC program, it was decided that U.S. participation would be limited to the programs involving the accelerator and the ATLAS and CMS experiments. At that time, U.S. physicists interested in B physics were much more inclined to work at the SLAC B Factory, which was already under construction. Beginning to participate in LHC-B now will be an unattractive option to U.S. physicists since the design of the experiment has been already completed, construction of the detector is in progress, and also the intellectual leadership of the experiment has been already established. If participation in LHC-B is pursued, possible contributions from U.S. physicists will be significantly limited.

Option 4: Do nothing. The risks of doing nothing are varied. Failure to pursue a complete understanding of CP violation leaves the question of why the universe is dominated by matter unanswered. Important cross checks of LHC results, such as the possible discovery of supersymmetry, will not be done either. Furthermore, the center of accelerator-based high energy physics studies moves completely out of the United States until a new project such as the linear collider or a super neutrino beam is approved and constructed.

D. Constraints and Assumptions

1. Operational Limitations

There are no foreseen operational limitations in regard to effectiveness, capacity, technology, or organization. The criteria for the operation of this type of facility are well established from years of experience in operating the current FNAL colliding-beam detectors. Run II of the Tevatron remains the high priority for the next several years, and OHEP plans to manage BTeV in such way as to minimize any interference on Run II operations. OHEP plans to conduct an operations review at FNAL to determine that there are adequate resources, including staff with specialized technical skills to both construct BTeV and continue to successfully operate Run II. The reviews during the critical decision process will examine the installation schedule to ensure that BTeV can be installed with minimal effect on Run II.

2. Geographic, Organizational, and Environmental Limitations

Fermilab is located on 6,800-acre site in Batavia, Illinois, and managed by the Universities Research Association (URA). It currently operates the Tevatron accelerator and colliding beam facilities, which consist of a four-mile ring of superconducting magnets and two large multi-purpose detectors. The Tevatron accelerator is capable of accelerating protons and antiprotons to an energy of one trillion electron volts (1 TeV). It is currently the highest energy accelerator in the world. The expansion of the experimental program in order to explore this new science by capitalizing on the existing Tevatron collider is very cost effective. There is no other facility in the world at which this experiment could be located. The High Energy Physics program would either support this project at FNAL or would have to seek new concepts of how to satisfy this mission need elsewhere.

There are no foreseen geographic, organizational, or environmental limitations. FNAL has the organizational structure in place to manage projects of this type.

3. Standardization and Standards Requirements

The BTeV Project must conform to the applicable design and operational standards of the FNAL facility and conform to the project management guidance offered by the DOE O 413.3, *Project Management for the Acquisition of Capital Assets.*

4. Environment, Safety and Health

All work at the FNAL site will be conducted under its DOE-approved Integrated Safety Management system. FNAL will comply with the requirements of the National Environmental Policy Act (NEPA). Based on the nature of the BTeV Project, and its planned location in an existing building, impacts to the environment are anticipated to be minimal.

5. Safeguards and Security

The BTeV Project will not create any new security issues during design and fabrication. No laboratory safeguards and security requirements will need to be changed for operations. The facility is expected to be a low-hazard, non-nuclear facility. Access to FNAL is controlled to ensure worker and public safety and property protection. None of the work at FNAL is classified.

6. Project Interfaces and Interaction Requirements

There are two currently operating experiments at the Tevatron; therefore an objective of the BTeV project will be to minimize the impact to that ongoing research program at FNAL. The majority of the work can be carried on in parallel to the current experimental program. BTeV will be housed in an existing unoccupied experimental hall, so no civil construction is required. Tevatron magnets in the interaction region will be replaced with higher performing ones. To the extent possible installation activities will be scheduled to occur during accelerator maintenance shutdown periods.

The project will receive program guidance and funding from the Office of High Energy Physics (OHEP). A Project Management Team for the proposed project has been identified.

7. Affordability Limits on Investment

The BTeV preliminary Total Project Cost (TPC) range is $190-$230 million in then-year dollars. The current preliminary evaluation of OHEP is that fabrication of BTeV while operating the Tevatron for Run II and starting NuMI/MINOS cannot quite be accommodated within an FNAL budget that grows at a pace consistent with recent experience. Given the size of the BTeV TPC and its estimated funding profile, there could be either a need for up to a $15 million funding increase for the HEP program starting in FY 2006 or a comparable reduction in activities elsewhere in the program during FY 2006-2009.

OHEP plans an operations review of the FNAL Tevatron complex in spring of 2004 to obtain a more accurate estimate of the need and to search for possible efficiencies and redirections within the FNAL program. Possible redirections from the rest of the HEP program are expected to be limited.

Additionally, external funding options, such as funding from NSF and other countries, will be fully explored as part of the conceptual design effort.

8. Goals for Limitations on Recurring or Operating Costs

The cost of operating the BTeV detector should be comparable to operating one of the existing colliding beam detectors at FNAL. The detector operations budget for Fermilab is approximately $70 million in FY 2004 and supports two large detectors as well as a couple of small detectors.

There are no plans to increase the performance of the Tevatron beyond the current Run II plan. The cost of operation of the Tevatron complex is well understood (Tevatron operation costs are approximately $120 million in FY 2004). The Tevatron complex will be supporting both BTeV and neutrino programs for the period beyond FY 2010.

9. Legal and Regulatory Constraints or Requirements

The project will be in full compliance with all applicable federal, state, and local requirements. There are no known legal or regulatory issues that could impact the project.

10. Stakeholder Considerations

There are no significant stakeholder issues anticipated. The primary stakeholders in this project are those in the U.S. particle physics community who are pursuing B physics. They have been extensively involved in the planning for the project, and it is expected that the project will continue to attract university, national laboratory and international users. The National Science Foundation, through grants to university groups, and foreign collaborators are also expected to participate. DOE supported university researchers are also expected to participate. All have been involved in the planning of this project. FNAL also makes a major contribution to education at all levels. Approximately 3,000 Ph.D. degrees have been granted to date, based on work performed at FNAL, with another 300 in progress.

11. Limitations Associated with Program Structure, Competition and Contracting, Streamlining, and Use of Development Prototypes or Demonstrations

Adequate technical resources are available at DOE laboratories, collaborating universities, and industry to plan and execute this project on a competitive basis. Much of the expertise required in designing and fabricating the BTeV detector resides with FNAL and other collaborating institutions. In addition, other facilities including those at FNAL, universities, and private industry will be used in the R&D, manufacture, and testing of the components that make up the BTeV detector.

The BTeV Project would make use of existing DOE contracts supplemented with competitive procurements as needed. FNAL will be responsible for accomplishing the project under the terms of the contract with the DOE. The project is planning to use fixed-price fabrication subcontracts and equipment procurements when possible. The Integrated Project Team and Office of Science reviews will monitor progress.

E. Applicable Conditions and Interfaces

FNAL staff will play the lead in the BTeV Project, which aims to minimize the impact to the ongoing research program at FNAL. Communication between the laboratory and the BTeV collaboration will be essential. Many universities and some other laboratories have indicated interest in participating in the project. Financial contributions to the project are anticipated by other domestic and foreign institutions. Effective management structures will need to be established for these efforts to facilitate participation and communication.

F. Resource Requirements and Schedule

A modest amount of R&D funding is necessary to prepare a Conceptual Design Report (CDR). A reprogramming request is being prepared to support this in FY 2004. The preliminary estimated Total Project Cost (TPC)[1] range is $190-230 million in then-year dollars[*], including design, R&D, fabrication, project management, quality assurance, contingency, and installation. Contributions from non-DOE sources should be well defined by CD-2, making the determination of a DOE baseline cost, schedule, and scope possible. FNAL expects to redirect program funds toward the BTeV Project.

The following profile has been estimated for planning purposes only. Neither the profile nor the schedule has been approved at this time. The TPC range can be expected to change when the conceptual design is completed. It will then be reviewed by DOE for accuracy. Changes to the proposed schedule will have impacts on the cost profile. The FY 2005 OMB budget request includes R&D funds for this project. Project fabrication would begin in FY 2006.

[1] BTeV is identified as an MIE in the FY 2005 President's budget and has TPC=TEC.

Estimated Funding
(Then Year M$)[*]

	R&D	MIE
FY 2003	3	-
FY 2004	4	-
FY 2005	3.5	6.75[†]
FY 2006	1.5	33-38
FY 2007	-	45-55
FY 2008	-	45-55
FY 2009	-	45-55
FY 2010	-	15-20
Total:	**12**	**190-230**

The following table shows the preliminary milestone schedule for Critical Decisions.

Preliminary Critical Decision Dates

CD-0 Approve Mission Need	2nd quarter FY 2004
CD-1 Approve Alternate Selections and Cost Range	3rd quarter FY 2004
CD-2 Approve Performance Baseline	2nd quarter FY 2005
CD-3 Approve Start of Construction	2nd quarter FY 2006
CD-4 Approve Start of Operations	1st quarter FY 2011

G. Development Plan

The technical readiness of the project is high for this stage in the planning process, as recently determined by a FNAL internal review of the project that was conducted on October 21–23, 2003. The project's most technically aggressive components utilize technology first developed for the LHC experiments, CMS and ATLAS. The conceptual design of the interaction region magnets will benefit from the work done by FNAL on the LHC interaction region quadrapole magnets. The proposed data acquisition and filtering system has benefited from the usual rapid progress of computing technology.

By leveraging R&D from the recent LHC accelerator and detector projects, a significant amount of pre-conceptual R&D has been accomplished to date, so the relative maturity of the project is advanced. The time needed to complete a conceptual design is short—only four to six months. It should be possible to complete the Critical Decision 2 process by the middle of FY 2005 as shown above.

[*] Inflation rates used are the OMB non-pay inflation rates starting with FY 2003: 2.0%, 1.5%, 1.6%, 1.7%, 1.8%, 1.8%, 1.8%.
[†] Funds engineering design work to support the final design. Approval of Start of Construction occurs in FY 2006.